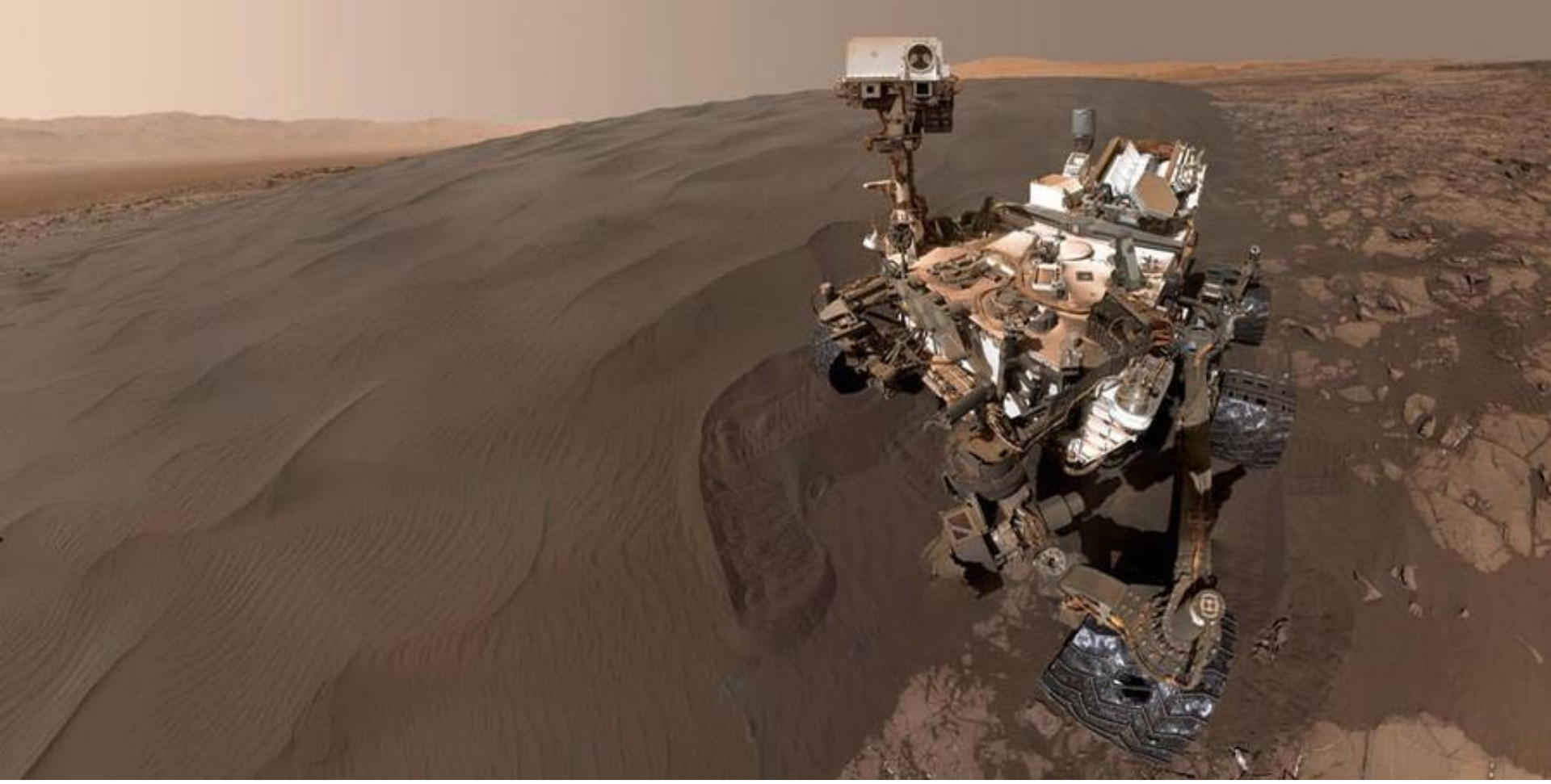


Where to Look? Predictive Perception with Application to Planetary Exploration

Kyohei Otsu, Ali-Akbar Agha-Mohammadi, Michael Paton
Presenter: Sisir Karumanchi
ICRA 2018

Jet Propulsion Laboratory
California Institute of Technology

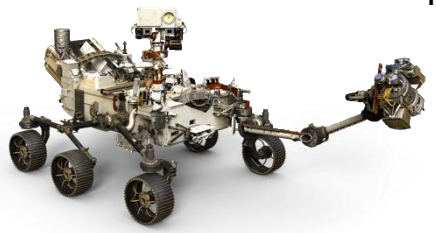
Introduction

Current

- Four rovers on Mars
- Looking for the evidence of life
  - Frequent stops for scientific interests
- Day-to-day operations
  - Planning tactical activities for 1-3 sols (Martian day) in a single ground-in-the-loop cycle
  - “Restricted sols” due to Earth-Mars time gap
- Limited use of AutoNav (autonomous navigation)

Future (2020 and beyond)

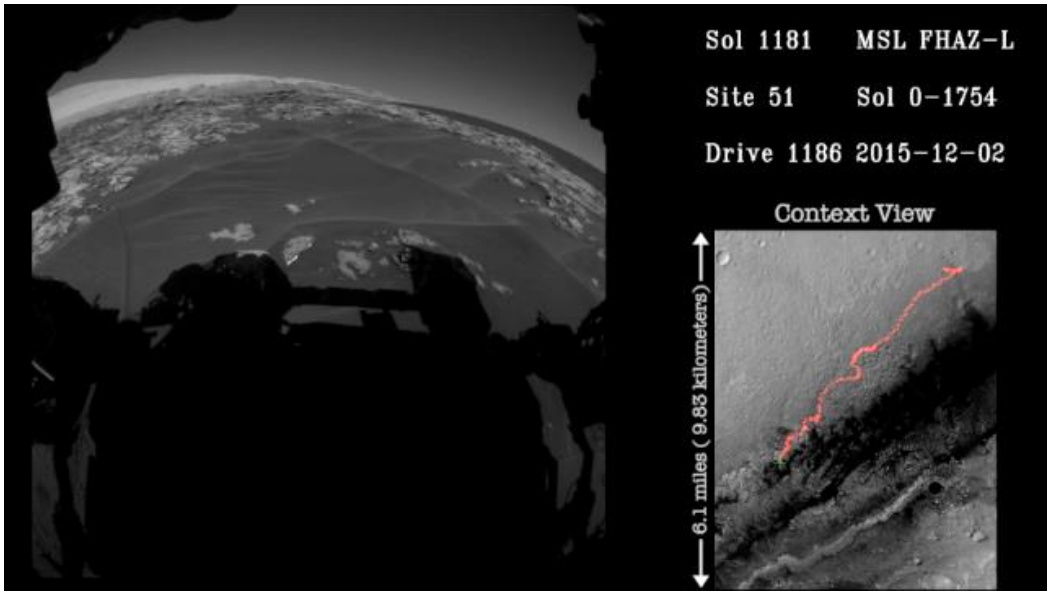
Mars 2020

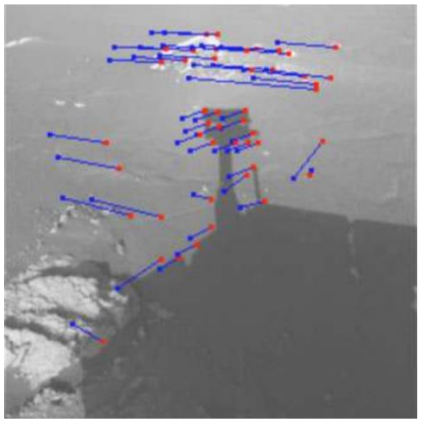


Mars Sample Return Fetch rover (concept)

- More drive-oriented missions
  - e.g., Collect sample tubes and return to the base before the launch chance
  - Travel far longer distance per sol
- Higher dedication to AutoNav
  - Drive beyond the line of sights
  - Drive on restricted sols
- Increased onboard resources
  - Vision-dedicated processors (Mars 2020) and multi-core general-purpose processors (future missions)

Computer Vision in Autonomous Navigation

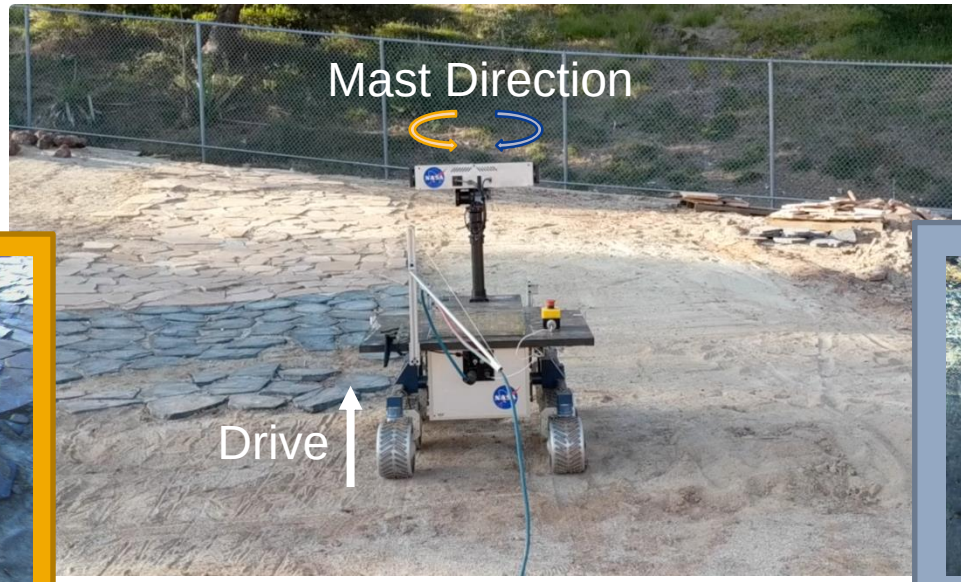




- Computer vision is a major source for autonomous navigation
- Today's vision system requires human intervention (e.g., manual mast pointing) to deal with challenges such as
  - Texture-poor terrain: Lack of salient features
  - Self-shadow: Confusion in visual feature tracking

Perception-aware Motion Planning

What is the best actions to maximize perception performance?



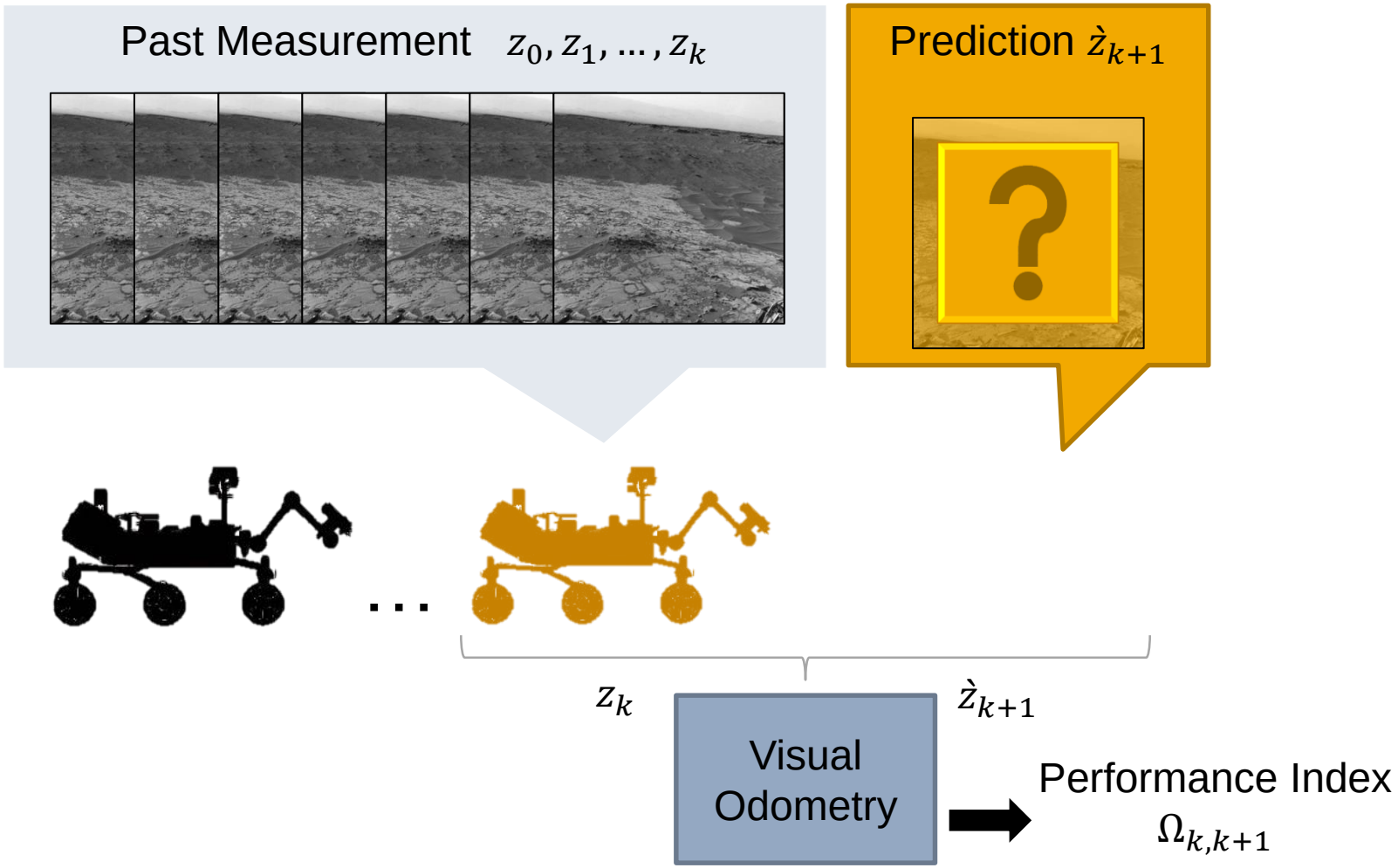
Key Technologies

1. Performance prediction with future measurements
   - Most-likely measurement prediction with stochastic map

2. Optimal mast trajectory planning
   - Spatio-temporal RRT*

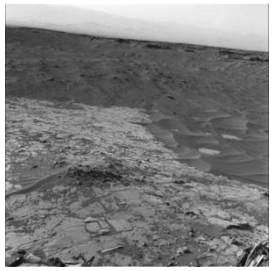
1. Performance Prediction

Quantize the performance of future measurements



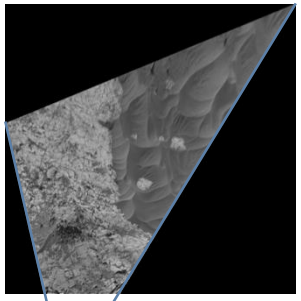
1. Performance Prediction

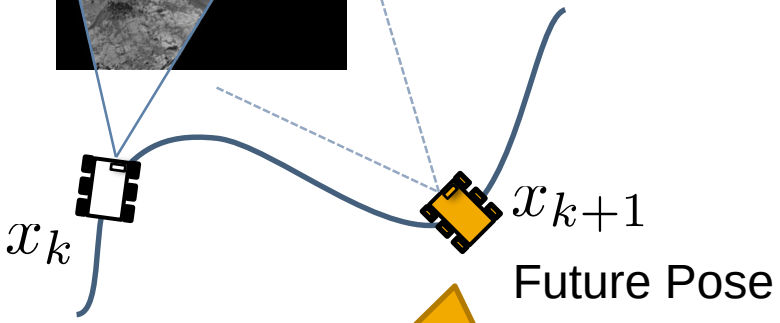
How to predict most-likely future measurement?



Measurement z_k

Orthogonal Projection

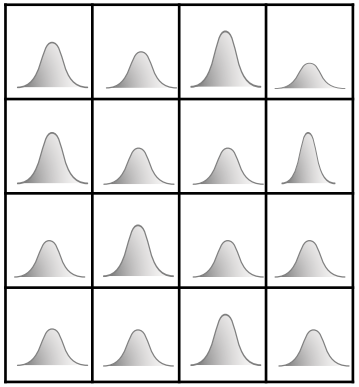




Future Pose

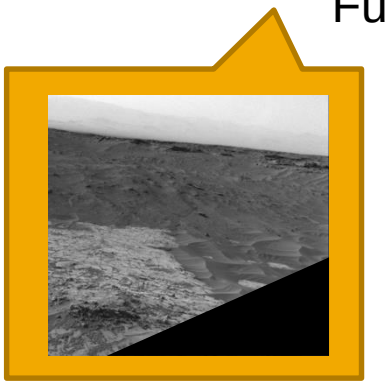
Belief Update

Map Beliefs



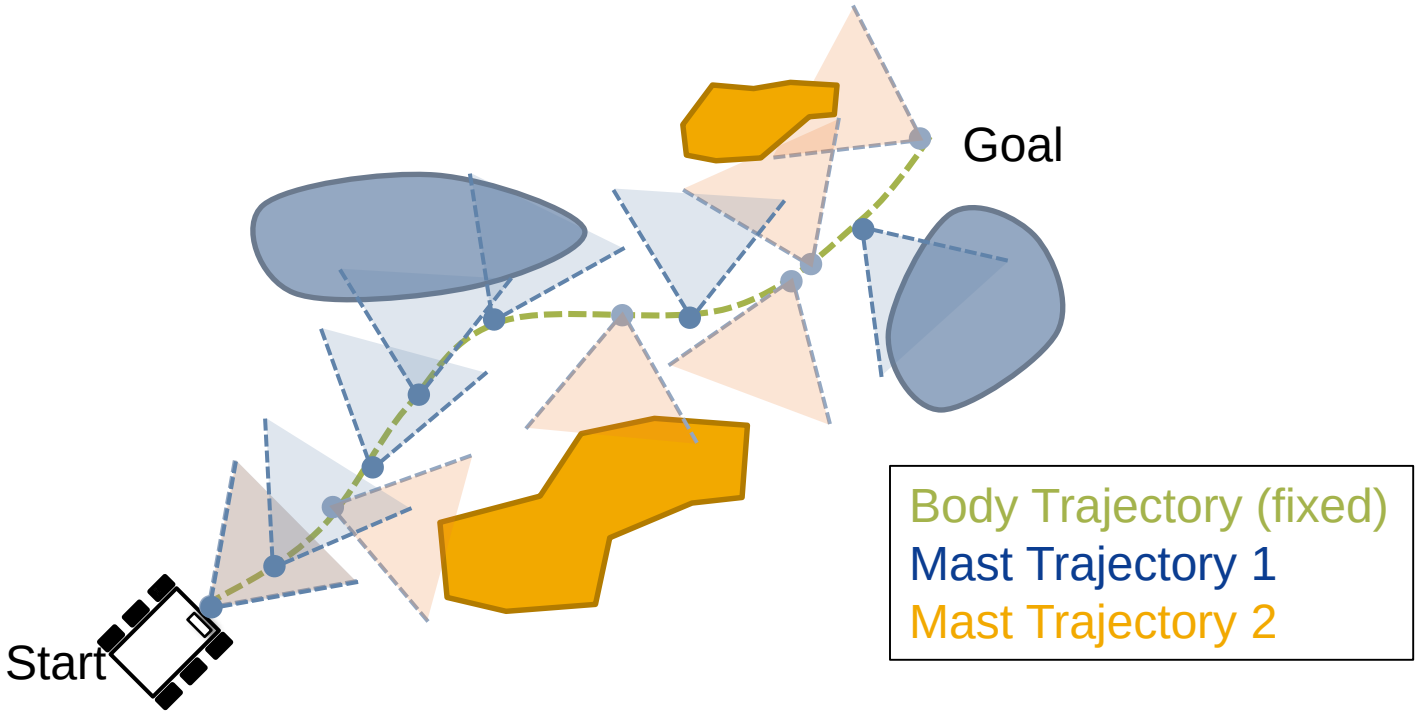
$p(m|z_{0:k}, x_{0:k})$

Most-likely Image Prediction



$$\grave{z}_{k+1} = \arg\max_{z_{k+1}} p(z_{k+1}|m_k, x_{k+1})$$

2. Mast Trajectory Planning



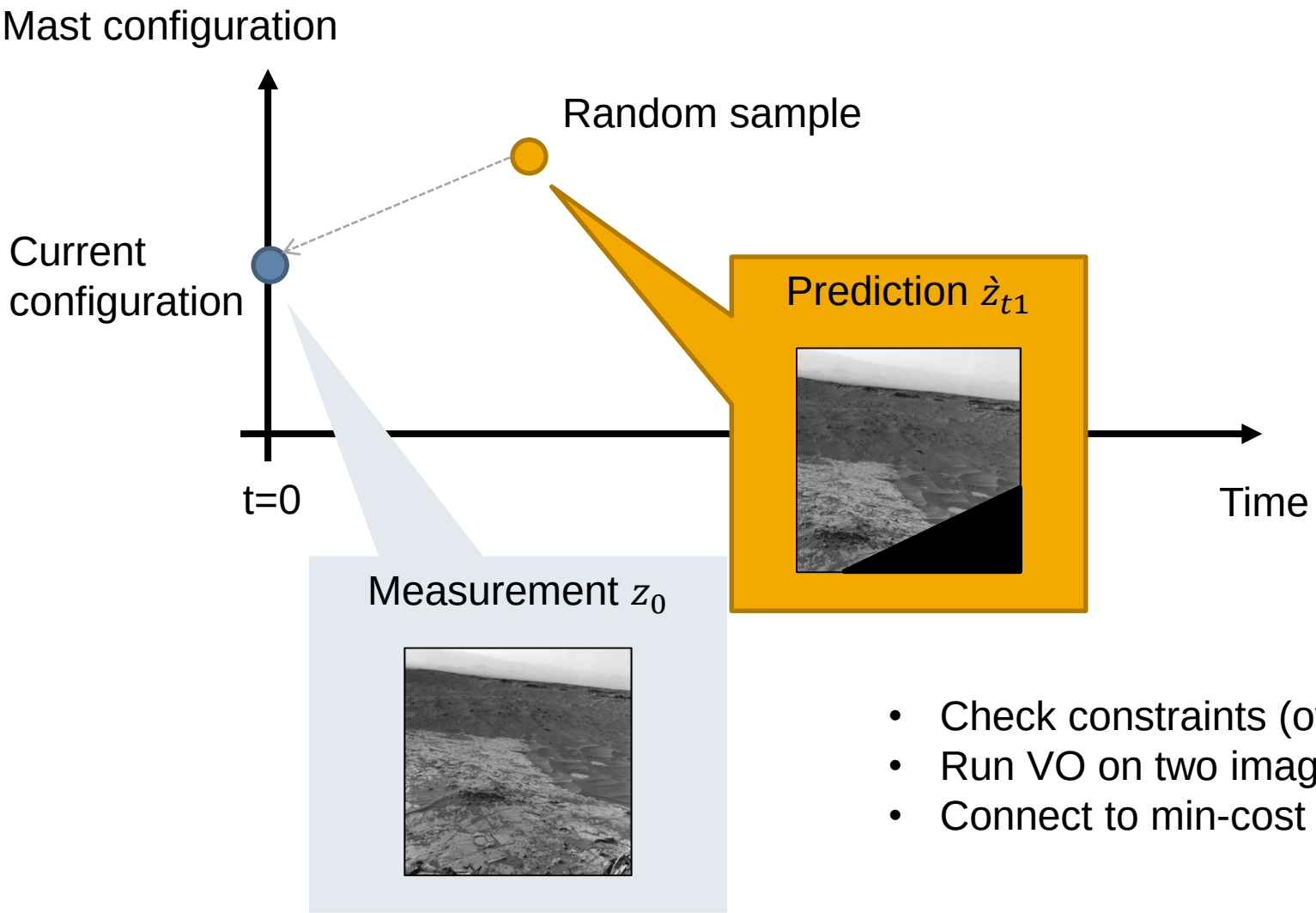
Mast state: (Pan, Tilt, Time)

Where to point mast?

When to take image?

2. Mast Trajectory Planning

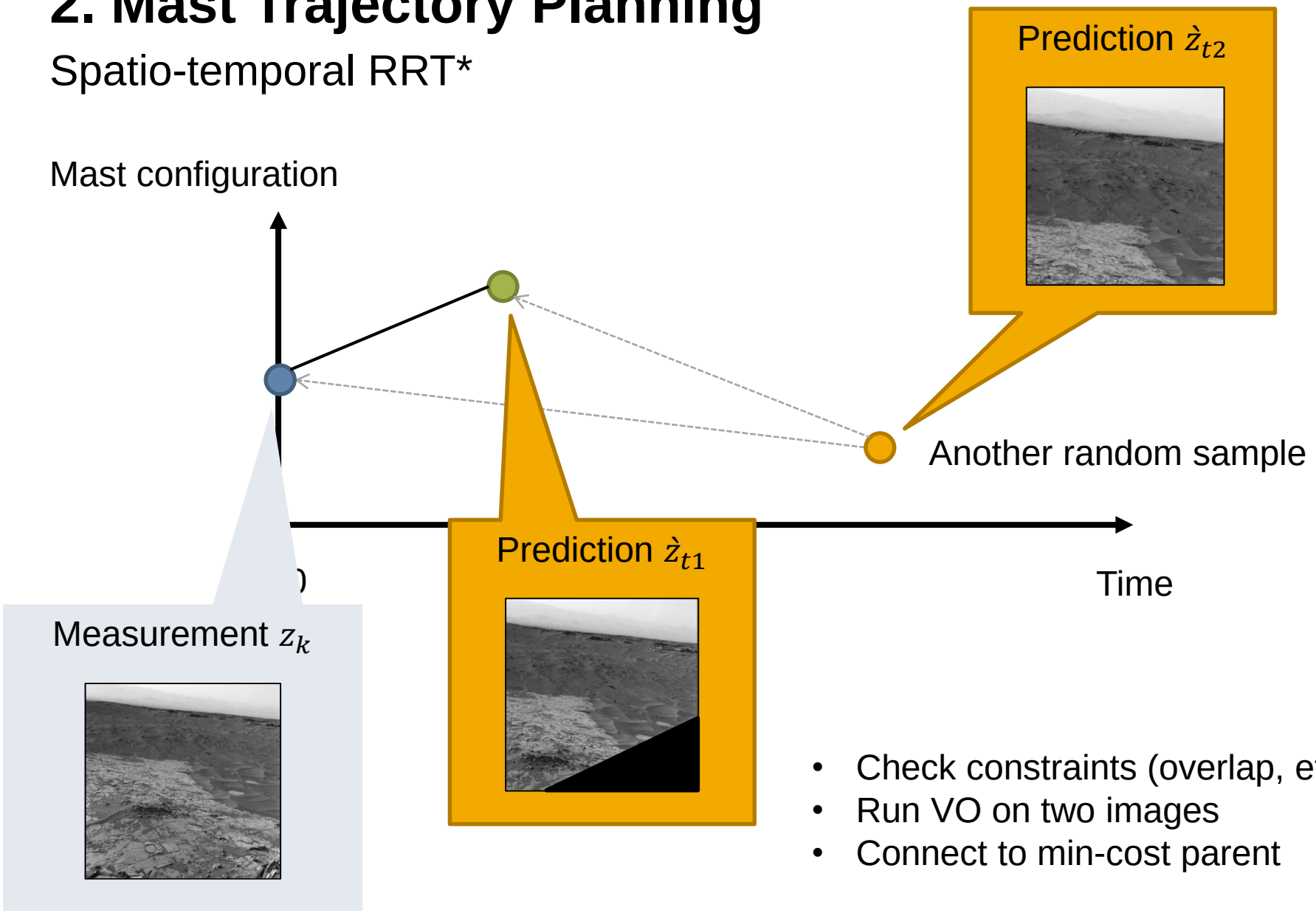
Spatio-temporal RRT*



- Check constraints (overlap, etc.)
- Run VO on two images
- Connect to min-cost parent

2. Mast Trajectory Planning

Spatio-temporal RRT*

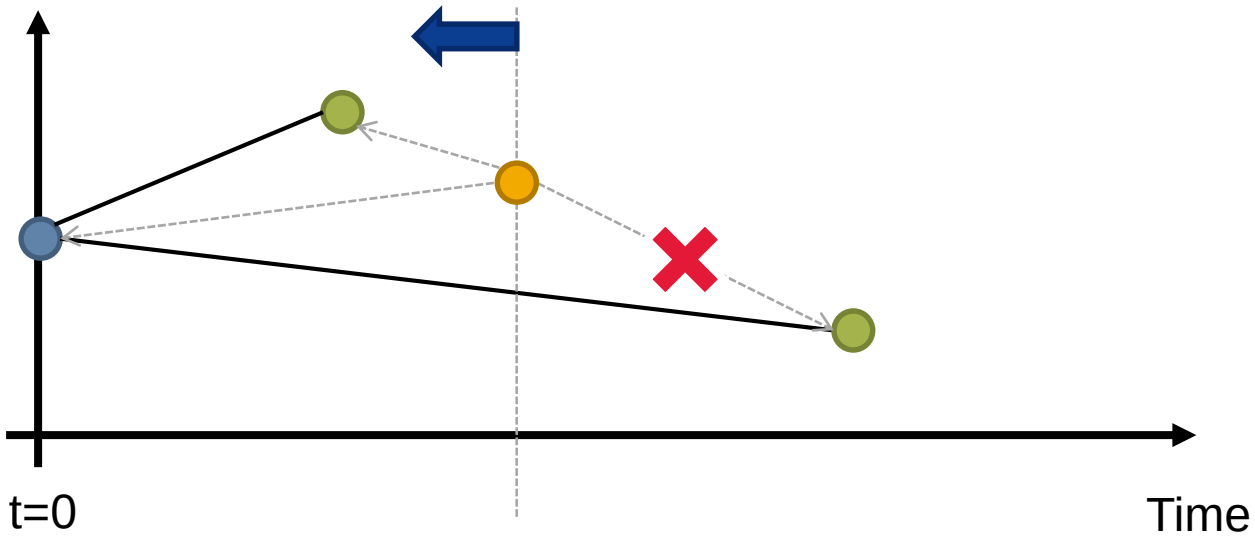


- Check constraints (overlap, etc.)
- Run VO on two images
- Connect to min-cost parent

2. Mast Trajectory Planning

Spatio-temporal RRT*

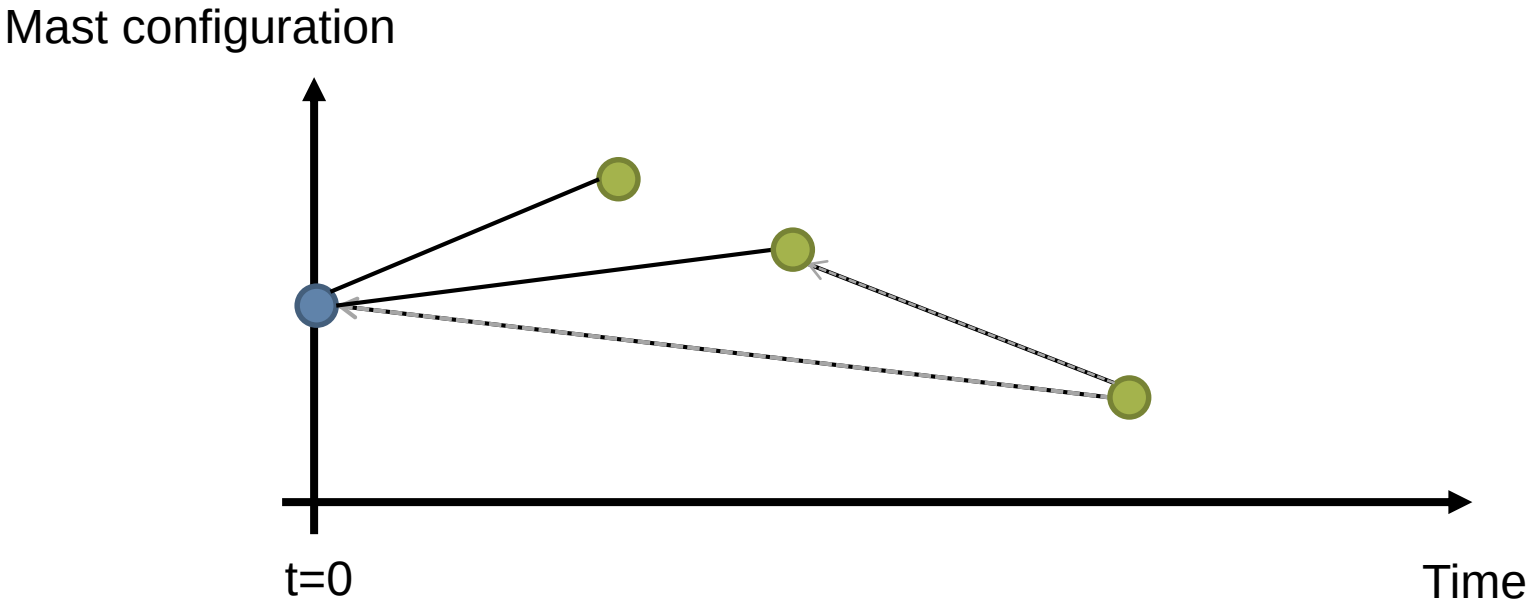
Mast configuration



- Samples must be connected in chronological order

2. Mast Trajectory Planning

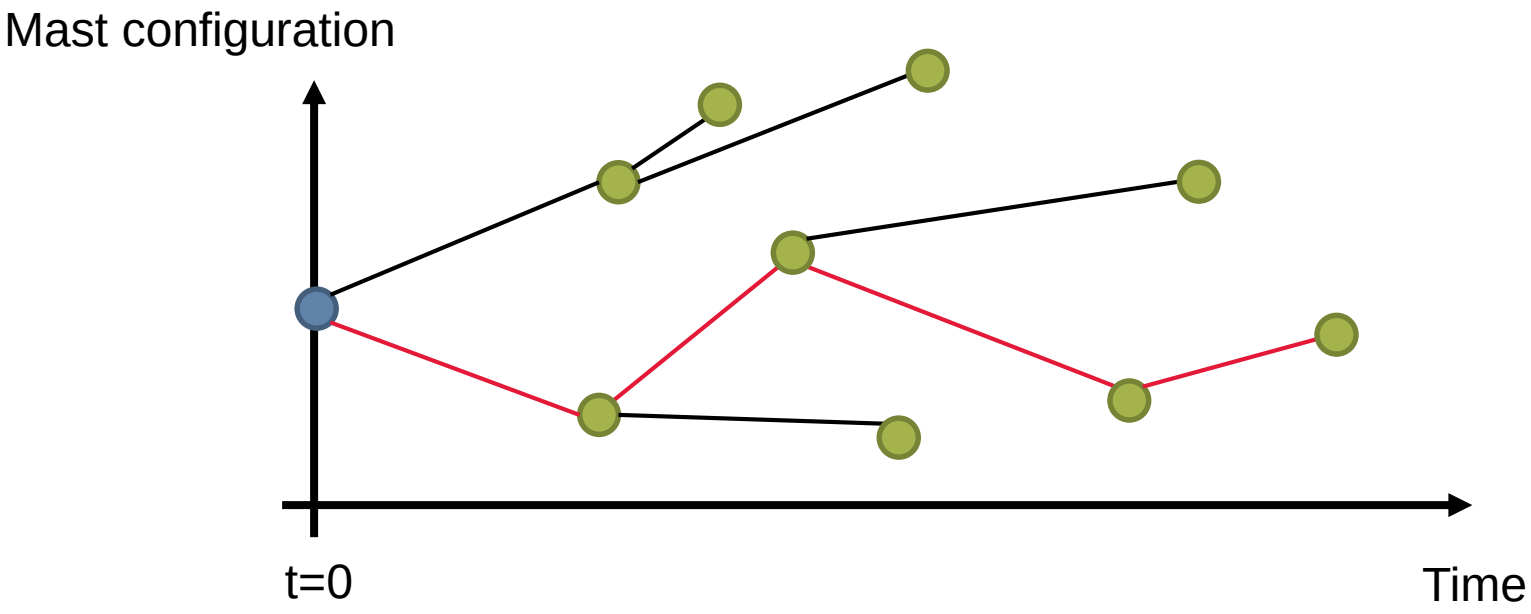
Spatio-temporal RRT*



- Rewire connections to always keep optimal tree

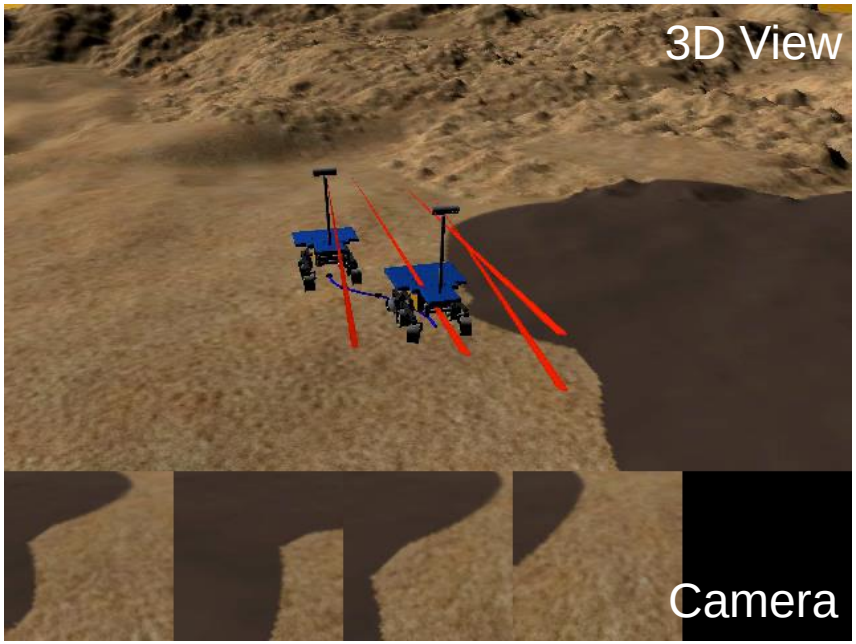
2. Mast Trajectory Planning

Spatio-temporal RRT*

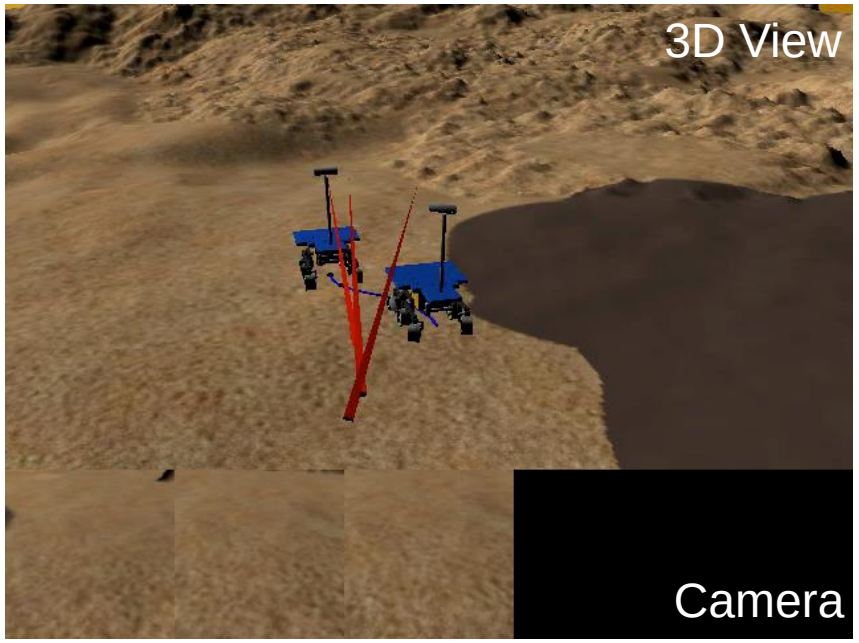


- Continue to grow the tree until it converges, or reaches max iteration
- A path with minimum leaf cost is the optimal mast trajectory

Simulation



Fixed mast (baseline)



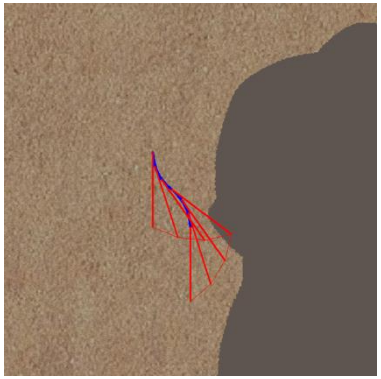
Proposed

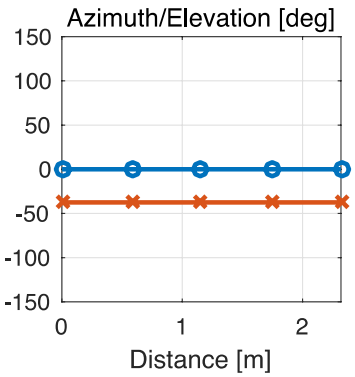
- JPL's DARTS/ROAMS Simulator
  - Used by past flight missions
  - Two regions: feature-rich (light) and feature-poor (dark)
- Performed spatio-temporal RRT* in receding horizon manner (5 m horizon)

Tree Evolution

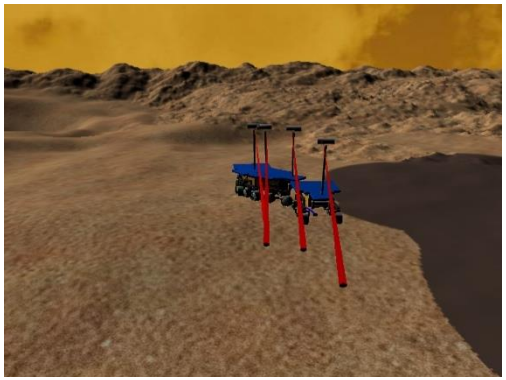
3D View | Planning Tree | Angle Profile

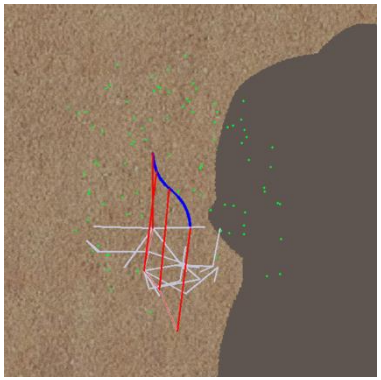
Fixed timing and direction (baseline)

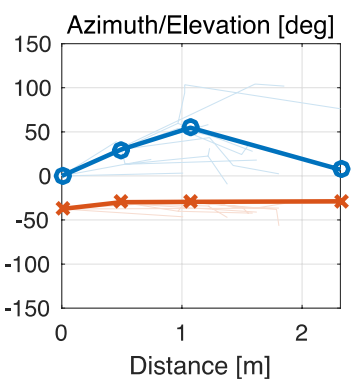




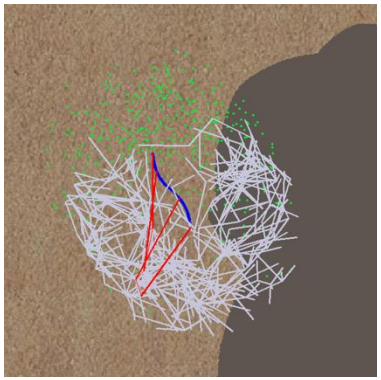
Iteration 120

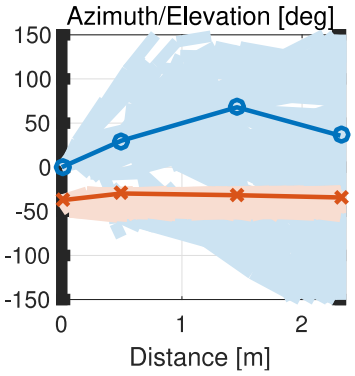






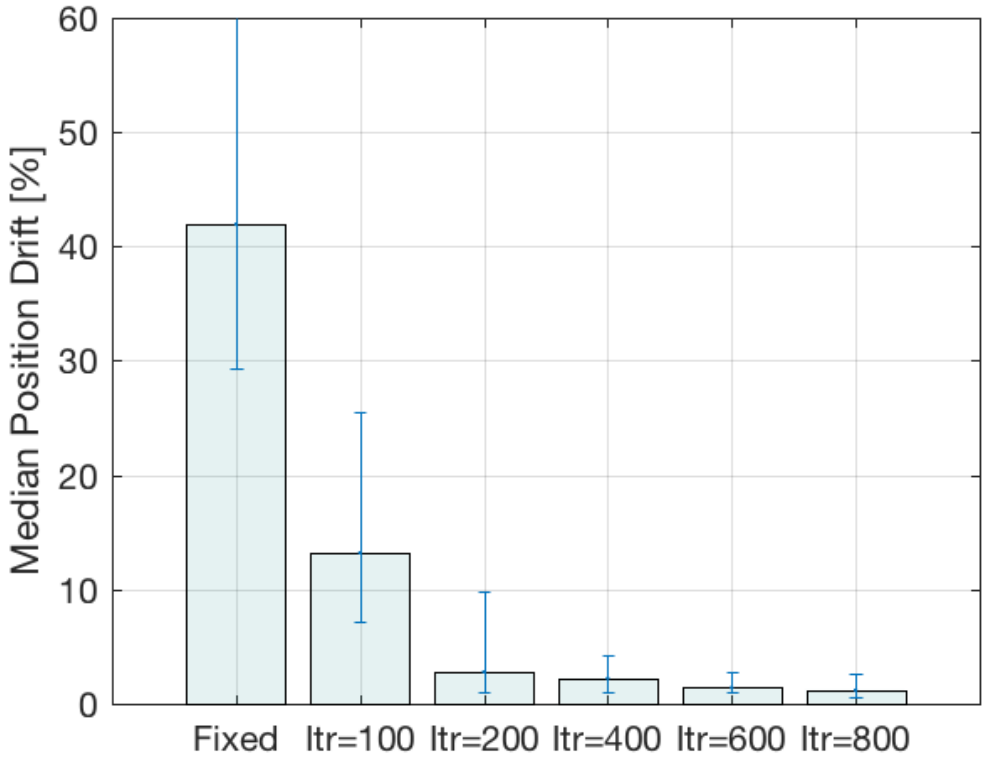
Iteration 800





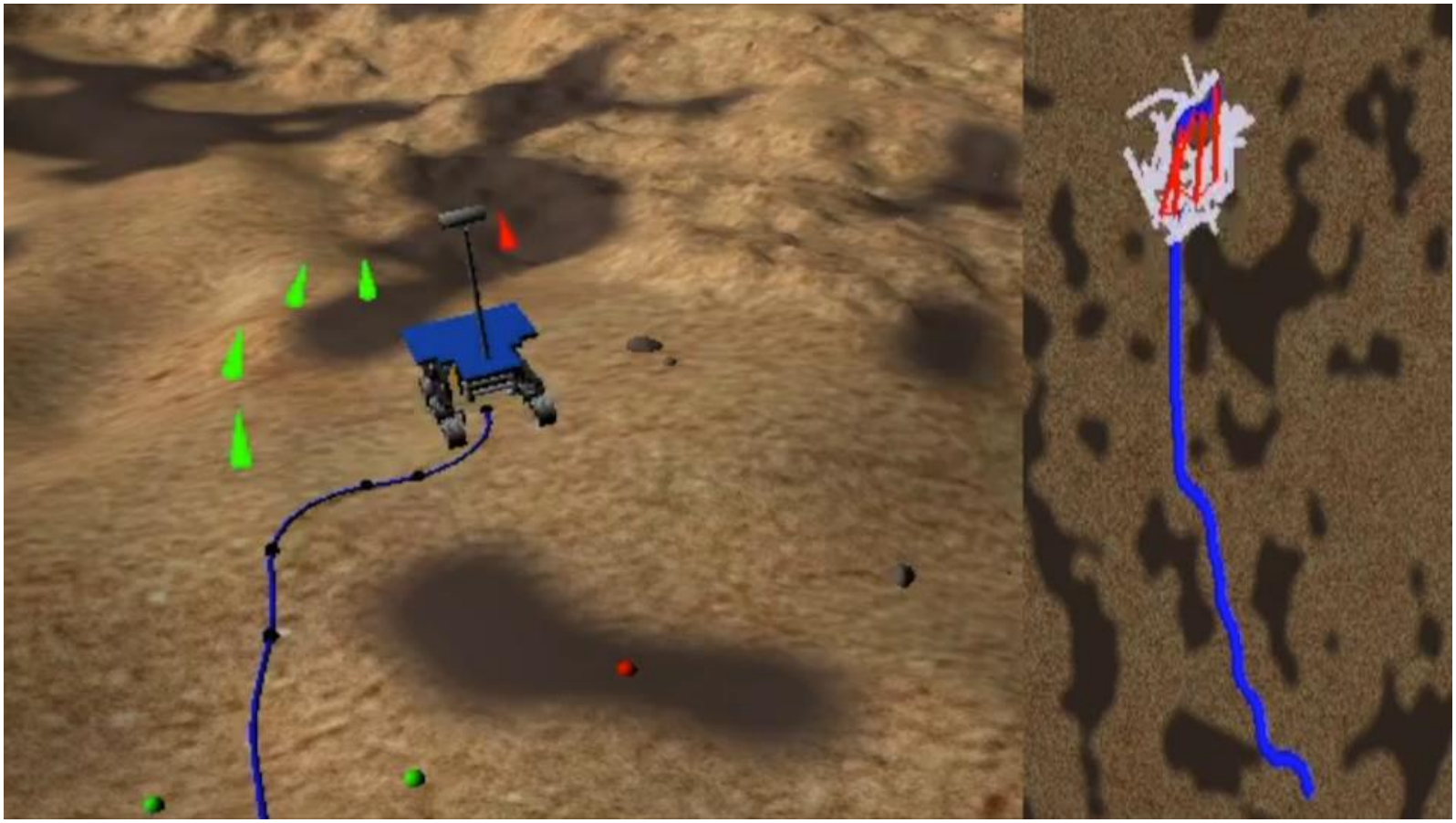
Position Estimation Error

Median error for 10 different maps



Receding Horizon Planning

Replan every step within 5m horizon



Contributions:

- Proposed a method to actively steer visual sensors to improve autonomous navigation performance
- Developed an online search algorithm of mast trajectories using predicted future camera views

Acknowledgement:

- The research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration

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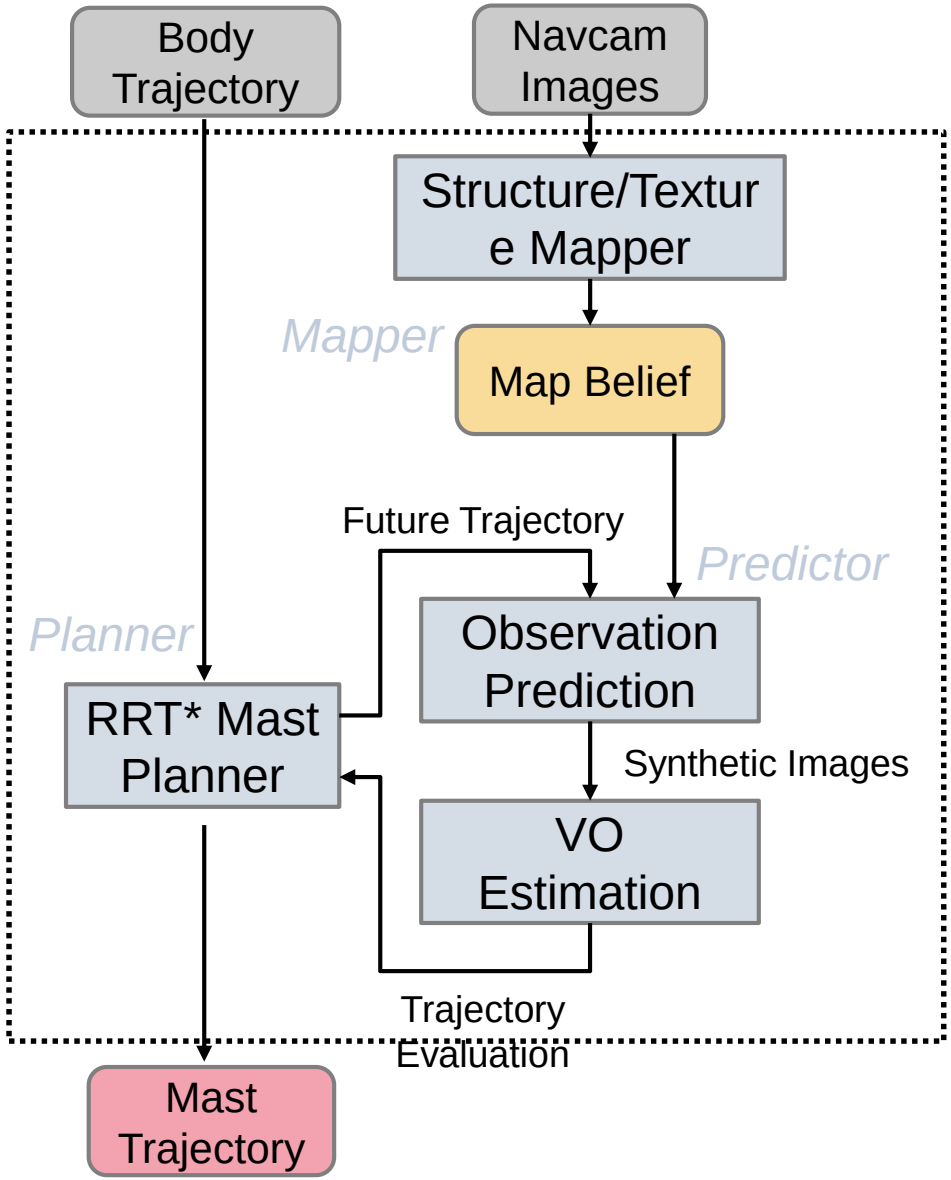
Data Flow


Body Trajectory
Navcam Images
Structure/Texture Mapper
Mapper
Map Belief
Future Trajectory
Predictor
Planner
Observation Prediction
RRT* Mast Planner
Synthetic Images
VO Estimation
Trajectory Evaluation
Mast Trajectory